Proceedings of the Integrated Crop Management Conference

Proceedings of the 11th Annual Integrated Crop Management Conference

Dec 2nd, 12:00 AM

Temperature and Drought Influence on Soybean Yield, Composition, and Seed Quality

Lance R. Gibson
Iowa State University

Russell E. Martin
Iowa State University

TEMPERATURE AND DROUGHT INFLUENCE ON SOYBEAN YIELD, COMPOSITION, AND SEED QUALITY

Lance R. Gibson, Assistant Professor
Russell E. Mullen, Professor

Department of Agronomy
Iowa State University

Research studies indicate an optimum temperature for soybean photosynthesis and yield near 86°F (30°C). Although the Corn Belt of the United States is one of the most productive soybean producing areas in the world, temperatures in this region are rarely centered on the ideal temperature at critical stages in soybean plant and yield development. Temperatures can vary widely within the region and fluctuate both diurnally and seasonally. The most critical stages of yield development in soybean occur when flowering is complete. Stress occurring anytime from R4 (full pod) to just after R6 (full seed), will reduce yields more than the same stress occurring at any other period of development. The period from R4.5 (late pod formation) to about R5.5 is especially critical because flowering becomes complete and cannot compensate, and because young pods and seeds are more prone to abort under stress than older pods and seeds. In addition, high temperatures during reproductive growth can alter soybean seed protein and oil composition and diminish the quality of seed used to plant the next season's crop.

Quantification of high temperature stress effects on soybean yield, composition, and seed quality

Several sets of studies have been conducted at Iowa State University to quantify reductions in soybean yield and seed quality and alterations in soybean oil and protein composition from high temperatures and drought during reproductive growth. Two of the sets are presented here. One set of studies determined the effects of combinations of day and night temperatures by using four temperature combinations. The control temperature was 86/68°F. Three elevated temperature treatments included 95/68, 86/86, and 95/86°F. In addition, the treatments were tested on three different growth phases: flowering and pod set (R1-R5), grain development and filling (R1-R8), and the entire reproductive period (R1-R8). A second set of studies focused on moderate and high temperatures in conjunction with low, moderate, and high water stress during grain filling.

For the day and night temperature studies, plants were initially grown in a greenhouse and were transferred to growth chambers when they reached beginning flowering (R1). Plants receiving temperature treatment during R1-R5 were transferred to 86/68°F for the remainder of the reproductive period. Plants exposed to treatments during R5-R8 were grown at 86/68°F during flowering and pod set (R1-R5). Yield components, seed composition, and seed quality were measured at maturity. Seed quality measurements included a standard germination test and an accelerated aging germination test, which analyzes seed vigor and storability. Seed was artificially aged for 48 hours at 106°F on elevated wire mesh trays above water in plastic boxes. The seed was germinated at the end of the aging period.

Treatments in the high temperature and drought studies were imposed at beginning seed fill (R5) and maintained until physiological maturity (R7). For application of temperature treatments, soybean plants were grown at optimum or high temperature in greenhouses. Water stress treatments were applied using a trickle irrigation system. The control, well-watered treatments were applied by bringing the pots containing these plants to near saturation once each day. The moderate and severe water-stress treatments received 75 and 50% of the amount of water applied to the controls, respectively. Yield components were measured at harvest and seed composition and standard germination of the resulting seed were measured.

Flowering and pod set (R1-R5)

High temperatures during early reproductive growth (flowering and pod set) altered seed yield, but had no effect on composition or seed quality (Table 1). An increase in night temperature from 68 to 86°F at 86°F day temperature benefited final seed yield through enhanced pod and seed production. The increase in night temperature resulted in more pods at the elevated day temperature as well. But any benefit provided to final yield was offset by reductions in seeds per pod and seed weight. The increase in day temperature from 86 to 95°F decreased yields similarly at the two night temperatures. These reductions were mainly due to fewer seeds per pod and to a lesser extent from reduced seed weight. Plants partially compensated for the effects of the 95/86°F temperature during this period by extending the duration of seed filling by 2 days when compared with the 86/68°F (data not shown). The drought studies did not include this growth phase.

Grain development and filling (R5-R8)

Both temperature and drought had significant impact on soybean seed yield, composition, and quality when they were applied during grain development and filling. An assessment of day and night temperature influence on yield indicates that elevating night temperature from 68 to 86°F had no effect when day temperature was maintained at 86°F (Table 1). But, when day temperature was increased from 86 to 95°F yield was reduced at both 68 and 86°F night temperature. The combination of high day and night temperatures resulted in the greatest reductions. Yield loss from high temperatures during grain development and filling resulted exclusively from reductions in seed weight. The high day/night temperature increased seed filling duration by 4 days when compared to 86/68°F, so seed weight reductions resulted from reduced seed filling rates (data not shown).

Both day and night temperatures during seed growth were important in determining protein and oil concentrations of soybean seed. This suggests that protein and oil concentrations were under 24-h temperature control. Thus, the influence of temperature on seed protein and oil concentrations may best be explained by changes in mean daily temperature. When day and night temperature combinations were converted to mean daily temperature, protein concentration increased 1.8% as mean temperature increased from 77 (86/68°F) to 86°F (86/86°F) and then stabilized from 86 to 91°F (95/86°F) (Table 1). Declines in oil concentration of 1% occurred as mean temperature increased from 77 to 91°F.

Table 1. Yield components, seed protein and oil concentrations (13% moisture basis), and seed quality of soybean plants exposed to differing day and night temperatures during reproductive growth.

Growth Phase	Temp[1]	Yield	Pods	Seeds per Pod	Seed Weight	Seed number	Protein	Oil	Germination	Accelerated Aging Germination
	°F	% change[2]					%			
R1-R5	86/68						36.4	18.3	99	97
	95/68	-16	nc	-17	-9	-7	36.8	18.1	99	99
	86/86	+7	+13	nc	nc	+9	37.1	18.3	99	98
	95/86	-16	+14	-21	-9	-7	36.7	18.0	99	97
	$LSD_{0.05}$						0.9	0.7	3	4
R5-R8	86/68						36.4	18.3	99	97
	95/68	-14	nc	nc	-16	nc	37.0	18.7	94	90
	86/86	nc	nc	nc	nc	nc	38.2	17.7	95	89
	95/86	-23	nc	nc	-20	nc	38.2	17.3	74	59
	$LSD_{0.05}$						0.8	0.5	16	25
R1-R8	86/68						36.4	18.3	99	97
	95/68	-26	nc	-17	-19	-9	38.4	18.1	85	70
	86/86	nc	+17	nc	-11	+14	39.2	17.2	95	90
	95/86	-27	+19	-21	-26	nc	39.7	17.1	76	63
	$LSD_{0.05}$						0.5	0.2	14	28

[1]Day/night
[2]Percent change relative to 86/68°F

Seed quality was generally high at the three lower temperatures (86/68, 86/86, 95/68°F), but was noticeably reduced at the combined high day/night temperature (95/86°F). The accelerated aging test indicated that soybean seed produced at this high temperature had especially poor vigor and storability.

Drought in combination with high temperature was more detrimental to soybean yield than either drought or high temperature alone (Table 2). An increase from temperature near optimum for soybean growth (84 or 81°F) to 95 to 91°F resulted in a 23 to 29% reduction in final seed yield. These reductions were similar to those found when temperature was increased from 86/68 to 95/86°F in the day/night temperature study. At the lower temperature, drought stress decreased yield 38 to 47%. But when high temperature and drought stress were combined the yield reductions were as great as 75%. These yield cuts resulted from declines in seed number and seed weight. Losses in seed weight from were due in part to a shortening of seed fill. The duration of seed filling was generally unaffected by temperature conditions when plants were well-watered. Drought decreased seed filling duration at both optimum and high temperature. Drought in combination with high temperature resulted in the greatest reduction in the duration of seed fill, decreasing it by as many as 17 days when compared with optimum conditions.

At daytime temperatures near optimum for soybean growth, protein content increased as intensity of drought increased. Soybeans that developed under severe drought stress contained 1.7 to 4.3 percentage points more protein than seeds from control plants. The increased protein from drought was accompanied by a reduction in oil concentration. Oil concentration was 1.1 percentage points less in seed produced under drought in both years studied. Increased drought stress had the same effect at the high daytime temperatures. When averaged across years, severe drought increased protein 2.7 percentage points and decreased oil 1.1 percentage points. Air temperature during seed fill also impacted the chemical composition of the soybean seed. Well-watered (control) plants grown at the higher air temperature produced seed with more protein and less oil. Differences were even larger when plants were grown under drought stress in elevated temperature. When averaged across years, 5.7 percentage points more protein and 3.9 percentage points less oil were contained in seeds from plants exposed to severe drought and high temperature during seed fill.

Table 2. Yield components, protein and oil concentration (13% moisture basis), and germination of soybean plants exposed to drought and high-temperature stresses during seed fill.

Year	Temp (°F)	Drought stress level	Yield	Seed number	Seed weight	SFD[1]	Protein	Oil	Germination
			% change[2]			days	%		
1	84	Control				39	33.7	21.1	92
		Moderate	-31	-20	-8	36	34.1	20.4	93
		Severe	-47	-33	-21	32	38.0	20.0	91
	95	Control	-29	-21	-10	37	36.1	20.4	80
		Moderate	-57	-35	-35	29	39.3	18.1	73
		Severe	-75	-48	-52	22	40.9	15.3	53
		$LSD_{0.05}$					0.8	0.6	5
2	81	Control				35	32.5	21.7	90
		Moderate	-17	-10	-9	30	32.5	21.8	88
		Severe	-38	-27	-15	29	34.2	20.6	87
	91	Control	-23	-25	-18	31	33.1	22.1	88
		Moderate	-31	-26	-20	28	34.6	21.1	86
		Severe	-55	-41	-36	22	36.7	19.7	86
		$LSD_{0.05}$					1.1	1.0	2

[1]Seed filling duration
[2]Percent of control drought level at the lowest temperature for each year.

At near optimum temperatures for soybean growth, drought had little impact on seed quality as measured by a standard germination test. In the first year study, the 95°F temperature significantly reduced germination and the reductions were larger as drought level increased. In the second year study, the 91°F high temperature was not great enough to adversely impact germination. The results indicated that temperature above 91°F were needed to get significant reductions in soybean seed quality and that high temperature combined with severe drought was more harmful to quality than high temperature alone.

The combined effects of high temperature and drought may be explained through the ability of the plants to maintain their tissue temperature below the air temperature. Theplants dissipated high heat loads through evaporation, so that leaves of a well-watered crop were cooler than the air temperature. But once a water deficit occurred in the stress treatment, the leaf temperatures became greater than air temperature. Thus, plant tissue temperatures were greater under high temperature and water stress than under high temperature and ample moisture supply.

Entire reproductive period (R1-R8)

High temperatures during early reproductive growth (flowering and pod set) altered seed yield, composition and seed quality (Table 1). The drought studies did not include this growth phase.

Since yield reductions from high day and night temperatures during the entire reproductive period appeared to be a combination of effects seen during early (R1-R5) and late (R5-R8) reproductive growth, the temperature effect during these two periods was additive. In other words, high temperatures that continued during the entire reproductive period did not result in greater yield loss than would be expected from the combination of loss from high temperature during R1-R5 or R5-R8. In addition, little yield compensation to temperature stress during flowering and pod set was occurring when stress was relieved during grain development and filling. When temperature treatments were applied R1-R8, seed filling duration was 5 days longer at 95/86°F than at 86/68°F, but seed filling rates were reduced by as much as 33% by the higher temperature (data not shown).

Alterations in protein and oil concentration were generally greater when plants were exposed to high temperatures during R1-R8 than R5-R8, indicating that the duration of the temperature treatments was important for seed composition. When day and night temperature treatments were applied during R1-R8, the protein concentration increased 3.3% and oil decreased 1.2% as mean temperature increased from 77 to 91°F (Table 1).

Seed quality reductions from high temperature during R1-R8 were similar to those seen during R5-R8 with one exception. The temperature increase from 86/68°F to 95/68°F during R1-R8 reduced both germination and accelerated aging germination. These results indicated that this temperature was more detrimental when it occurred for the duration of reproductive growth than when it occurred just during grain development and filling.

Conclusions

These studies quantified the final seed yield, composition, and quality obtained from soybean under high temperature and/or drought stress during critical periods of soybean reproductive growth. Generally, temperature conditions during flowering and pod set had little influence on seed composition or planting quality. Seed yield was negatively affected by high day temperature during these early reproductive growth periods through reductions in seeds per pod and to a lesser extent from lower seed weight. Yield reduction in these studies was as great as 16%. Elevated night temperatures during flowering and pod set increased yield by as much as 7% through greater pod set.

Higher than optimum temperature during seed development and filling decreased yield by as much as 29%. Drought stress decreased yield as much as 47% at optimum temperatures for soybean growth. A combination of elevated temperature and severe drought stress was most detrimental and decreased yield by up to 75%. In day/night temperature studies, yield reductions from high temperature during seed development and filling resulted exclusively from lowered seed weight. In high temperature and drought studies, yield was reduced through fewer and smaller seeds. Protein concentration increased both with higher temperature and drought and was greatest under combinations of high temperature and drought. Conversely, oil level decreased with temperature and drought and was greatest with the combined stresses. Drought in the absence of high temperature had little influence on seed quality. Germination was decreased as many as 25 percentage points by higher than optimum temperature and a combination of drought and high temperature decreased germination up to 39 percentage points.

A full assessment of stress effects on soybean yield, composition, and quality requires knowledge of the timing of critical soybean stages during the growing season. Table 3 includes the start, end, and mean dates for various soybean growth stages averaged for the 1992 through 1996 growing seasons. These dates indicate that stages most susceptible to stress occur during the later half of August and early September in Iowa. A time of year when combinations of high temperature and drought stress can occur.

Table 3. Timing of soybean growth stages during the growing season in Iowa.

		Dates (Average 1992-1996)[1]			
Stage	Description	Start	End	Mean	Days After Flowering (R1)[2]
R1	Beginning bloom	June 21	Aug. 16	July 20	0
R3	Beginning pod	July 5	Aug. 30	Aug. 4	12
R5	Beginning seed[3]	July 22	Sept. 16	Aug. 21	31
R7	Beginning maturity	Aug. 30	Oct. 4	Sept. 13	62
R8	Full maturity[3]	Sept. 9	At Frost	Sept. 23	72

[1]Source: 1999 Iowa Agricultural Statistics.

[2]Source: How A Soybean Plant Develops, Spec. Report No. 53. Iowa State University Extension.

[3]Dates are estimated from Iowa Agricultural Statistics data for 1992-1996 and days after flowering reported in "How A Soybean Plant Develops".

References

Dornbos, D. L., Jr. and R.E. Mullen. 1991. Influence of stress during soybean seed fill on seed weight, germination, and seedling growth rate. Can. J. Plant Sci. 71:373-383.

Dornbos, D. L., Jr. and R.E. Mullen. 1992. Soybean seed protein and oil contents and fatty acid composition adjustments by drought and temperature. J. Am. Oil Chem. Soc. 69:228-231.

Dornbos, D. L., Jr., R.E. Mullen, and R.M. Shibles. 1989. Drought stress effects during seed fill on soybean seed germination and vigor. Crop Sci. 29:476-480.

Gibson, L.R., and R.E. Mullen. 1996. Influence of day and night temperature on soybean seed yield. Crop Sci. 36:98-104.

Gibson, L.R., and R.E. Mullen. 1996. Soybean seed quality reductions by high day and night temperature. Crop Sci. 36:1615-1619.

Gibson, L.R., and R.E. Mullen. 1996. Soybean seed composition under high day and night growth temperatures. J. Am. Oil Chem. Soc. 73:733-737.

Ritchie, S.W., J.J. Hanway, H.E. Thompson, and G.O. Benson. 1992. How a soybean plant develops. Spec. Rep. No. 53. Iowa State University Extension. Ames, IA.

Sands, J.K., and H.K. Holden. 1999. Iowa agricultural statistics. Des Moines, IA.